9th International Conference on Urban Climate, Toulouse, France during 20-24 July, 2015

Translating the Urban Heat Island effect into power consumption for space-cooling: A case-study of megacity Delhi

Anurag Kandya & Manju Mohan

Department of Civil Engineering,
Pandit Deendayal Petroleum University
Gandhinagar, India

Centre for Atmospheric Sciences,
Indian Institute of Technology Delhi,
New Delhi, India

**akandya@gmail.com*

¿ PARADOX ¿


The Sydney Morning Herald

EXTENT OF CRISIS REVEALED

20,000 die each day

It is axiomatic that
the more advanced the civilization becomes,
the more complex the problems related to men's environment will be.

THE WORLD IS URBANIZING

1800
Urban population: 2%

1950
Urban population: 30%

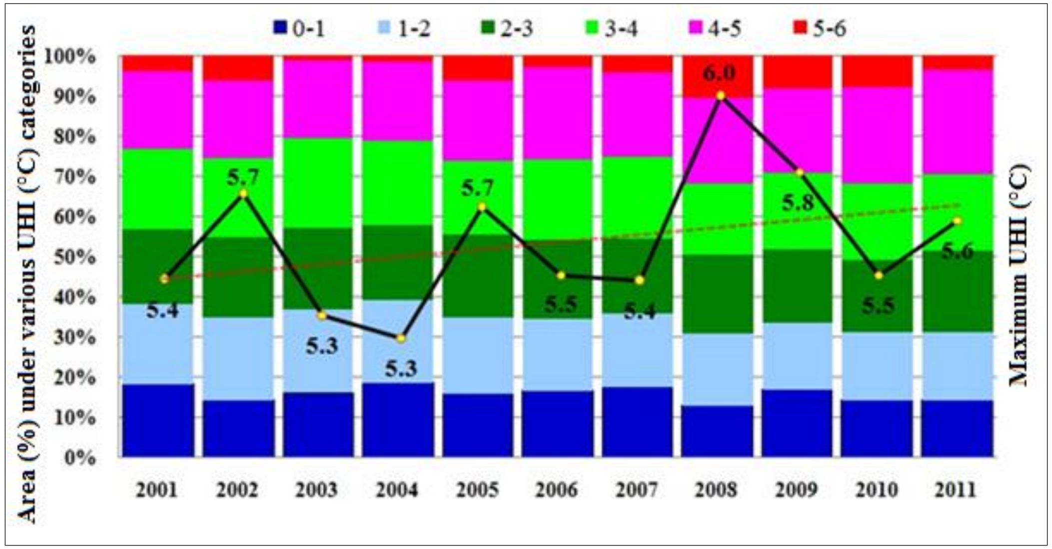
2030
Urban population: 60%

2000
Urban population: 47%

It is alarming to know that almost 180,000 people are added to the urban population each day!

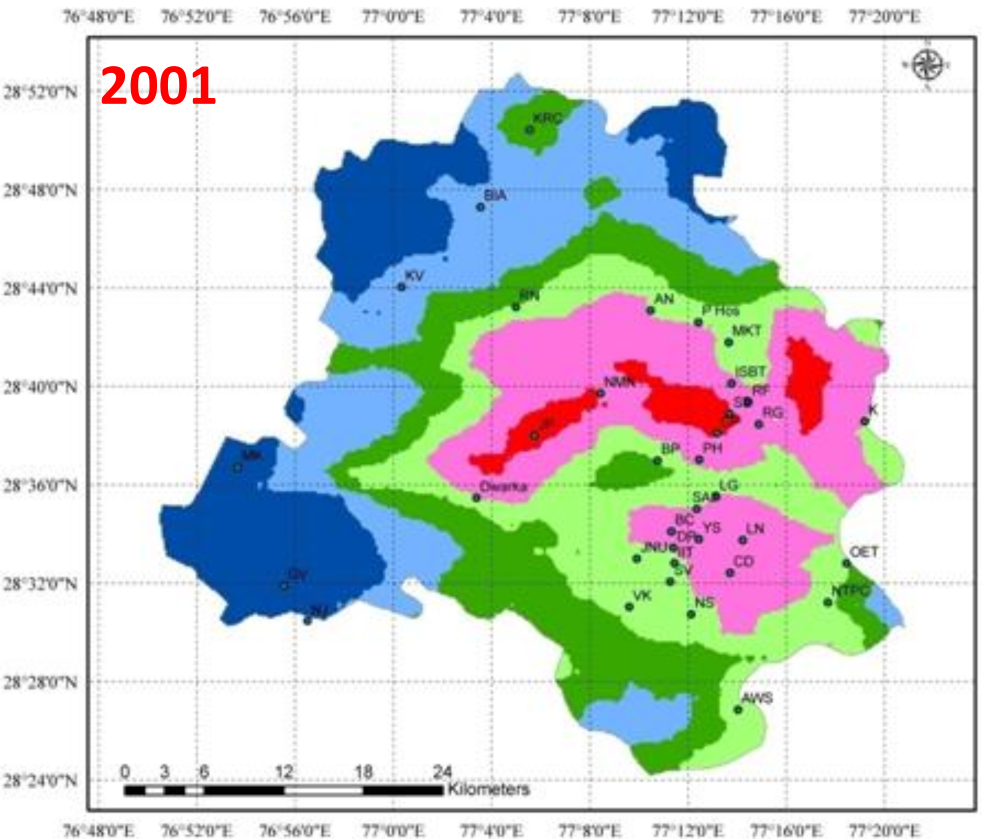
Urban Heat Island (UHI) is considered as one of the major problems in the 21^{st} century

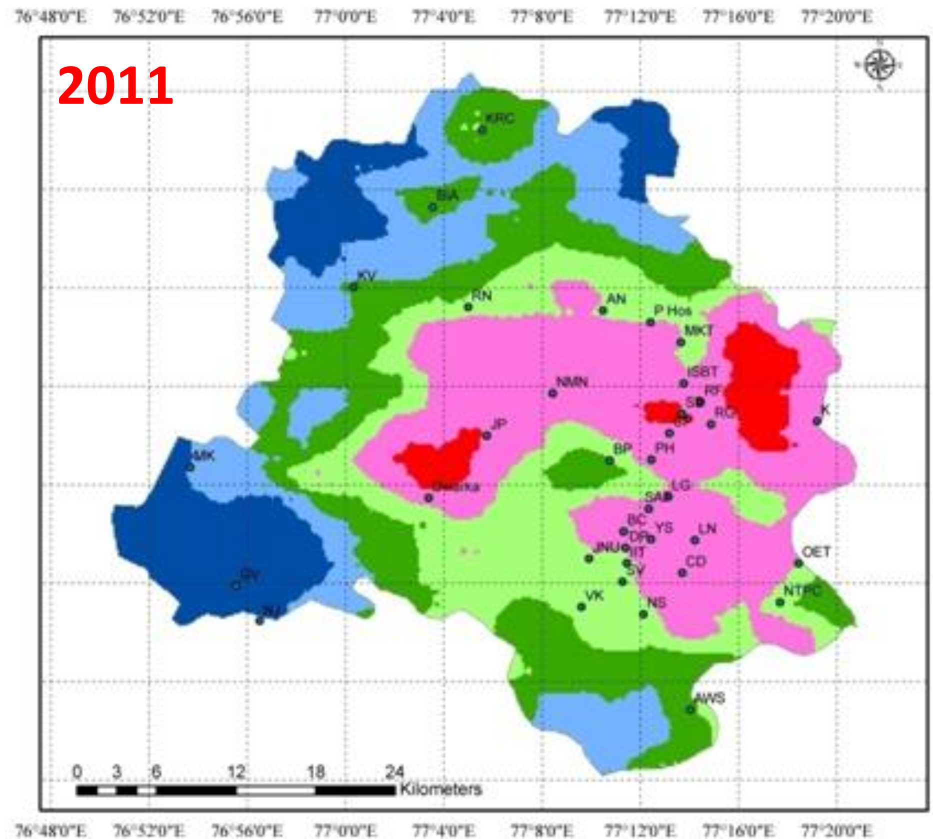
NIGHTTIME UHI



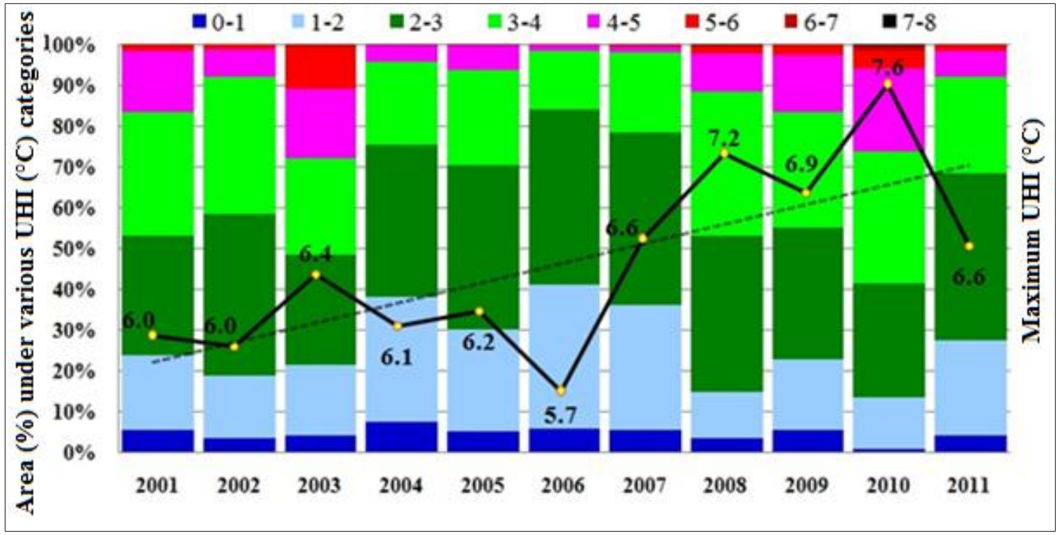
UHI (°C)

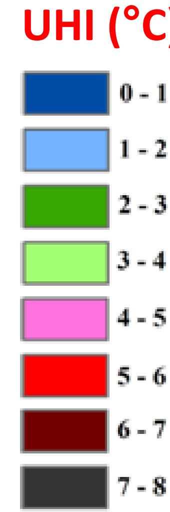
0 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6

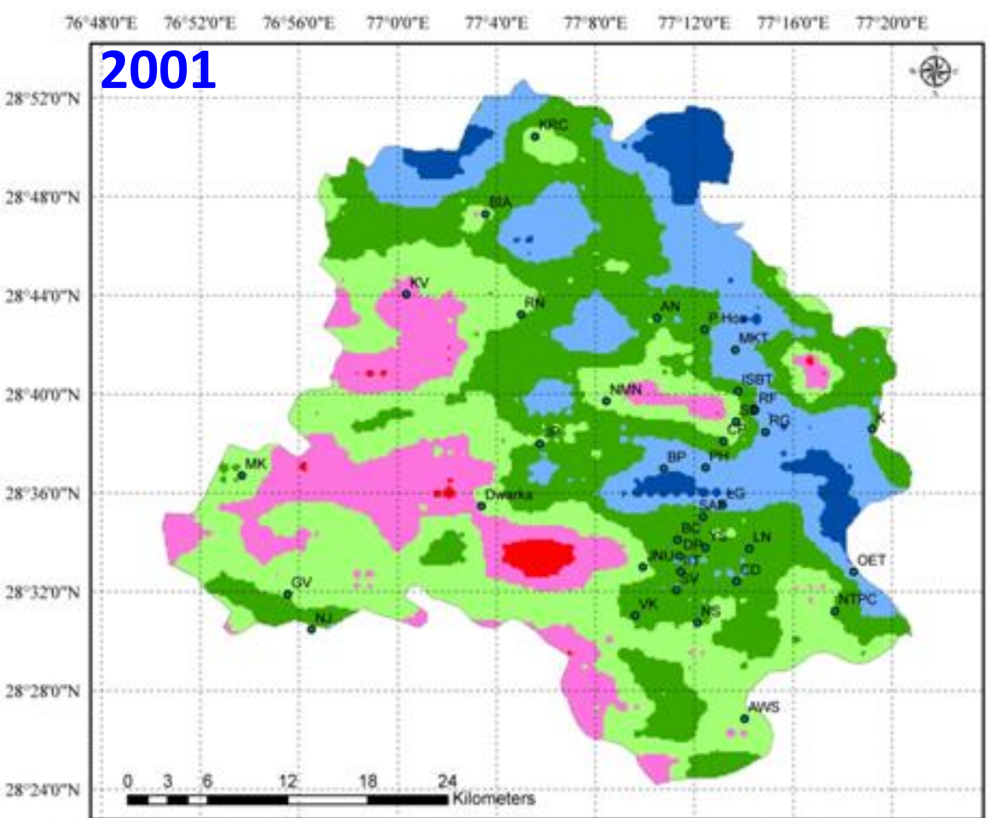


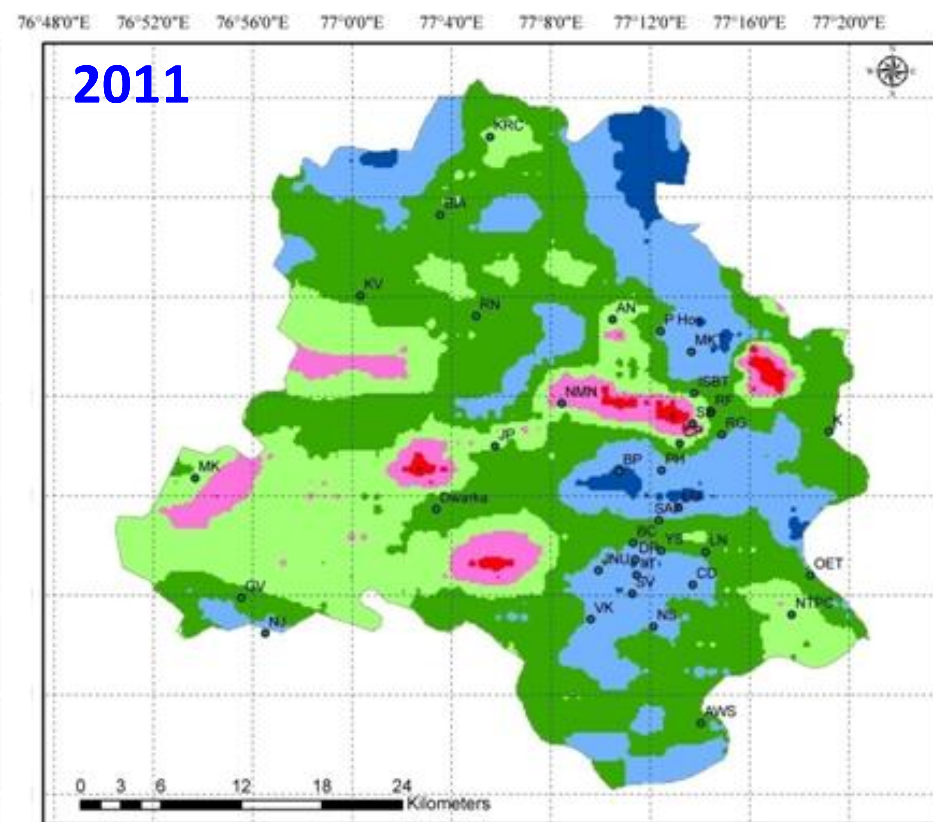


DAYTIME UHI

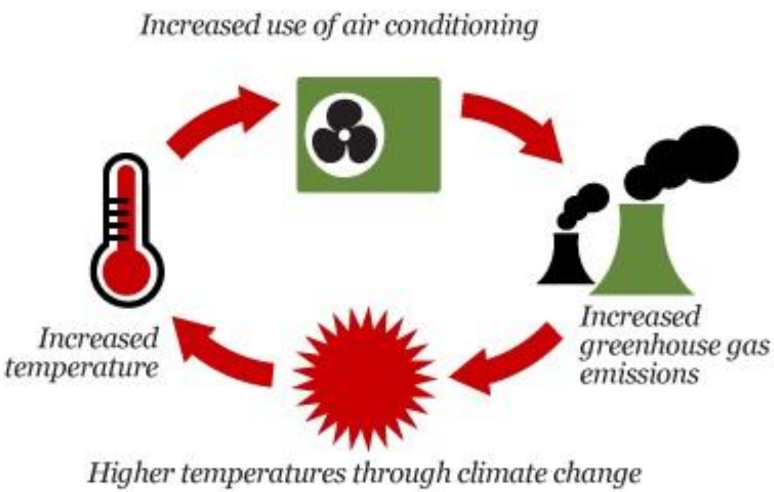

0-1
1-2
2-3
3-4
4-5
5-6
6-7
7-8
Area (%) under various UHI (°C) categories
Maximum UHI (°C)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
6.0
6.0
6.4
6.1
6.2
5.7
6.6
7.2
6.9
7.6
6.6
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011

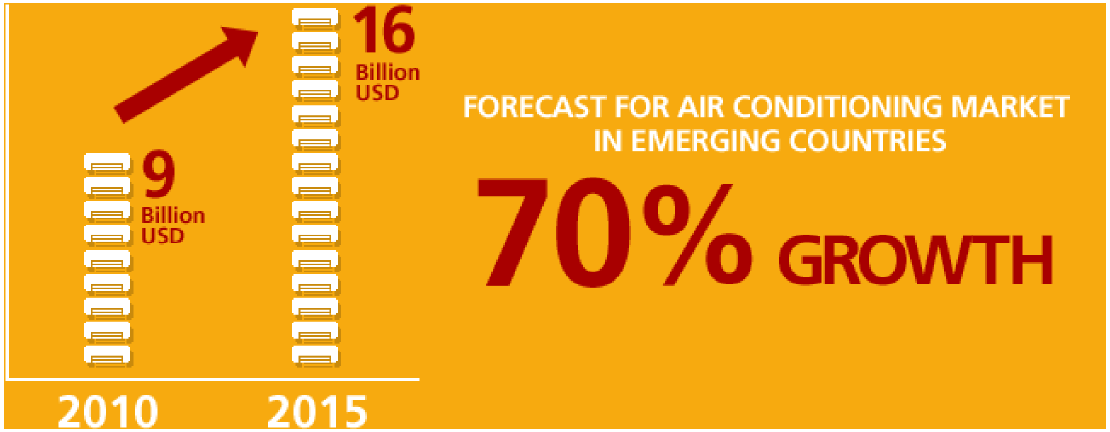

UHI (°C)
0 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8


2001
76°48'0"E
76°52'0"E
76°56'0"E
77°0'0"E
77°4'0"E
77°8'0"E
77°12'0"E
77°16'0"E
77°20'0"E
28°52'0"N
28°48'0"N
28°44'0"N
28°40'0"N
28°36'0"N
28°32'0"N
28°28'0"N
28°24'0"N
KRC
BIA
KV
RN
AN
MKT
ISBT
NMN
JP
MK
BP
Dwarka
OET
GV
NJ
VK
NS
NTPC
AWS
0
3
6
12
18
24
Kilometers

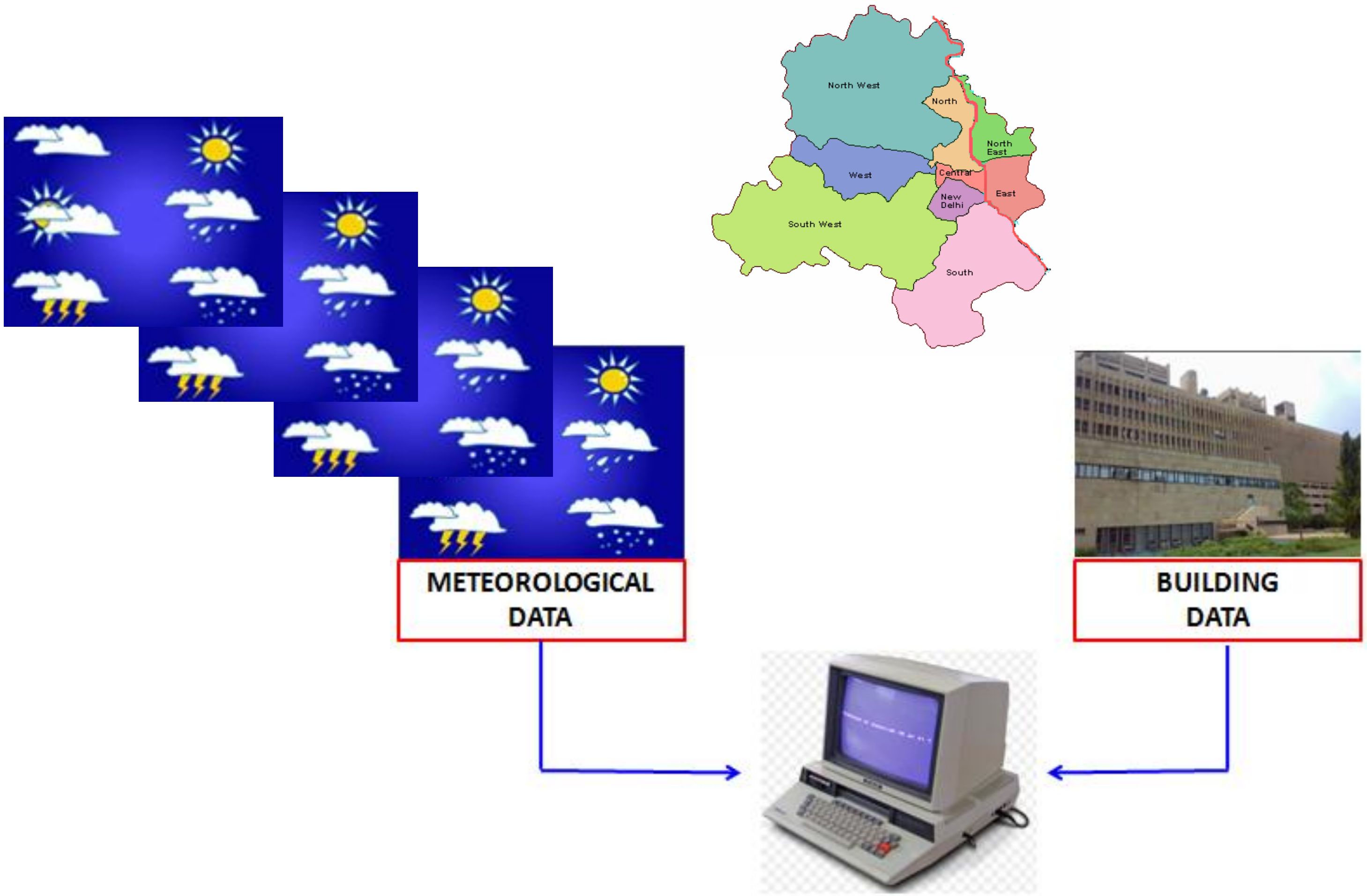

2011
76°48'0"E
76°52'0"E
76°56'0"E
77°0'0"E
77°4'0"E
77°8'0"E
77°12'0"E
77°16'0"E
77°20'0"E
KRC
KV
RN
AN
ISBT
NMN
JP
MK
BP
Dwarka
OET
GV
NJ
VK
NS
NTPC
AWS
0
3
6
12
18
24
Kilometers

VICIOUS TRAP !

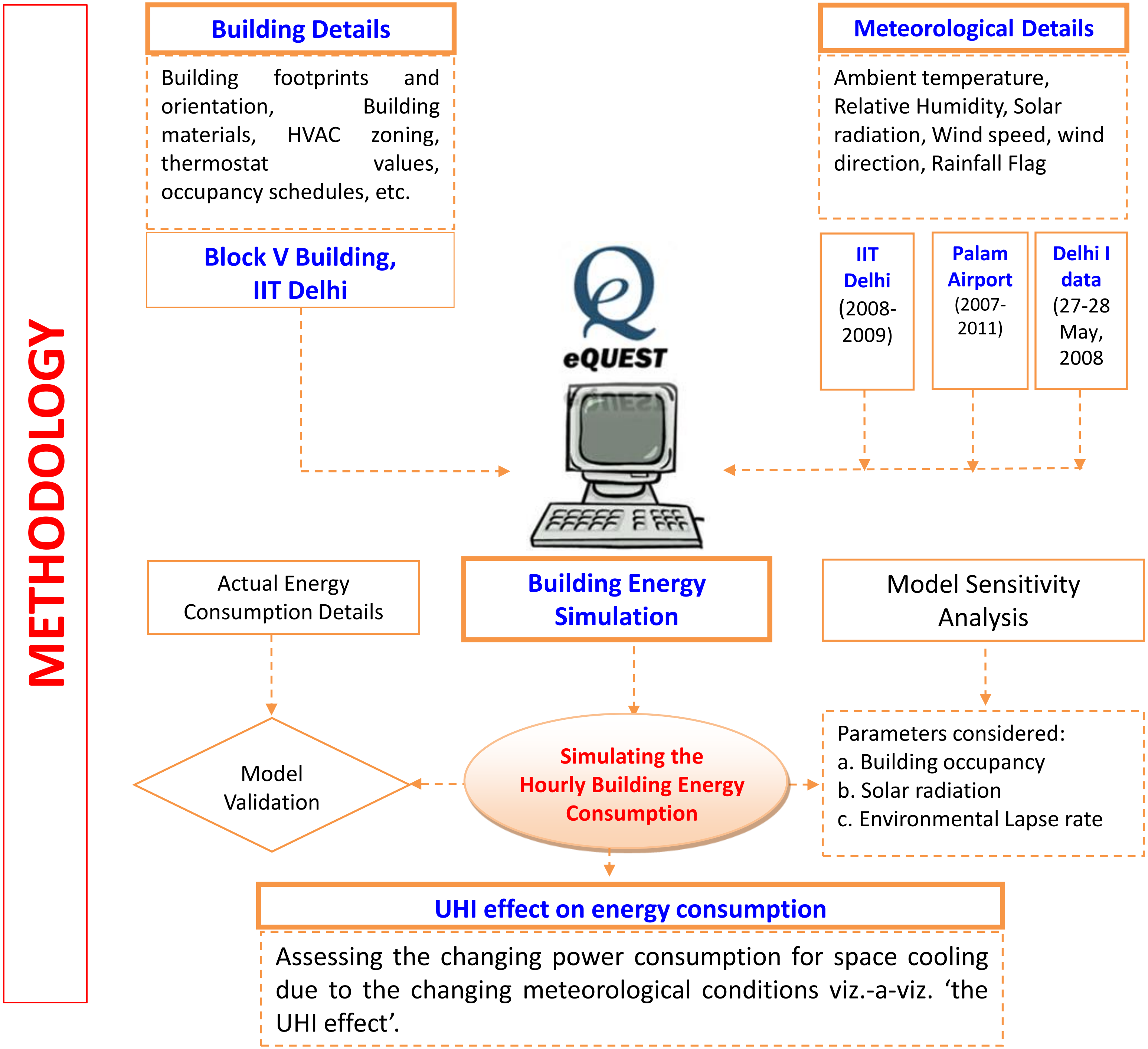




Source:
Daikin Industries, 2014



Building Energy Simulation under Multiple Microclimatic Scenarios

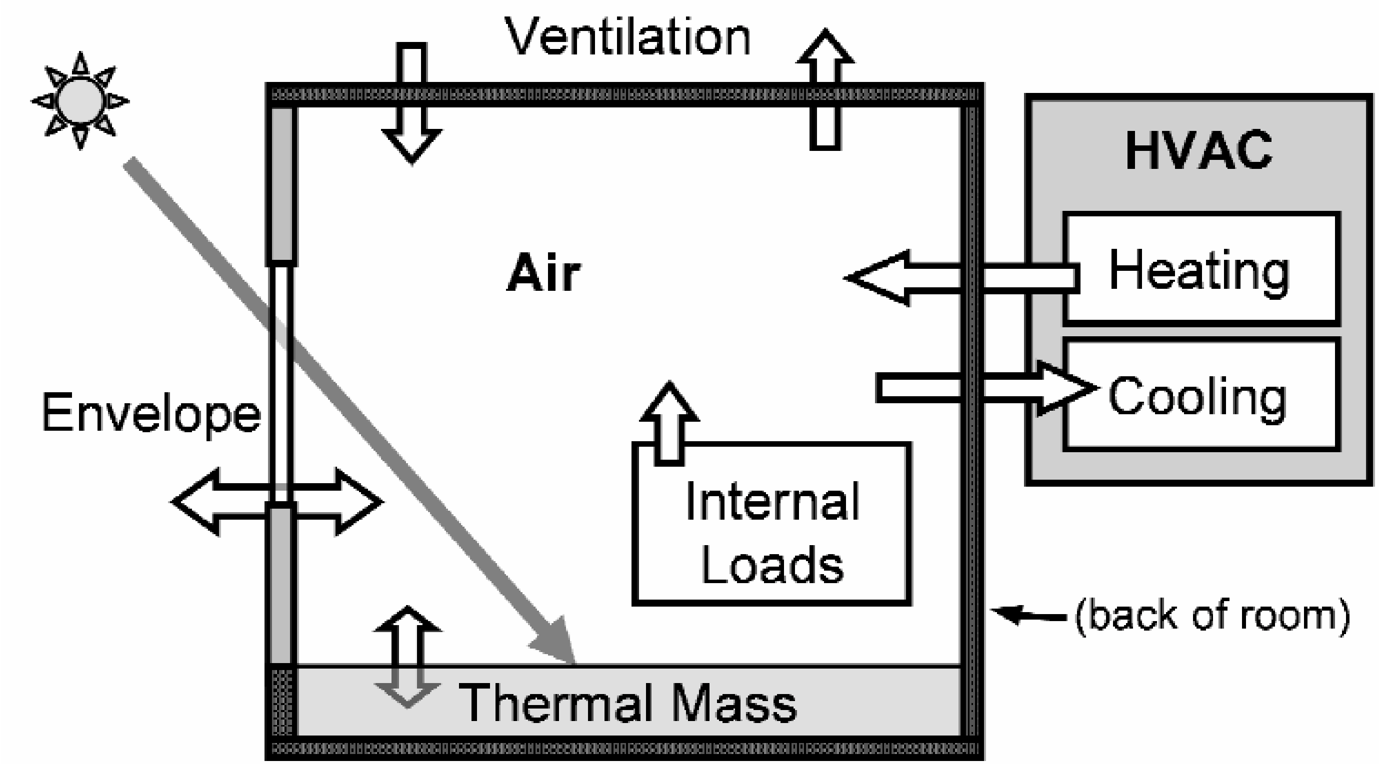

METHODOLOGY
Building Details
Building footprints and orientation, Building materials, HVAC zoning, thermostat values, occupancy schedules, etc.
Block V Building, IIT Delhi
Meteorological Details
Ambient temperature, Relative Humidity, Solar radiation, Wind speed, wind direction, Rainfall Flag
IIT Delhi (2008-2009)
Palam Airport (2007-2011)
Delhi I data (27-28 May, 2008
eQUEST
Actual Energy Consumption Details
Building Energy Simulation
Model Sensitivity Analysis
Model Validation
Simulating the Hourly Building Energy Consumption
Parameters considered:
a. Building occupancy
b. Solar radiation
c. Environmental Lapse rate
UHI effect on energy consumption
Assessing the changing power consumption for space cooling due to the changing meteorological conditions viz.-a-viz. 'the UHI effect'.

BEM used : eQUEST
Quick Energy Simulation Tool

- **eQUEST** program is the upgrade program of DOE-2
- **DOE-2** is the most widely recognized and respected building energy analysis program today which is developed by **Lawrence Berkeley National Laboratory** and the Associates of J.J. Hirsch, and supported by U.S. Department of Energy and Power Institute.
- It calculates hour-by-hour building energy consumption over an entire year (8760 h) using hourly weather data with location under consideration.
- Various researchers (Abraham et al., 2008; Jinghua et al., 2008; Jinghua et al., 2009; Zhu, 2006; Heiple and Sailor, 2008) have **successfully used eQUEST for simulating Building Energy Demand**

ENERGY BALANCE

Energy exchanges in a building occur via five channels: (i) internal loads, (ii) ventilation, (iii) envelope (iv) thermal mass and (v) HVAC



ENERGY BALANCE EQUATION

Assuming air is well-mixed within a zone, an energy balance on the air within a room can be written as

$$mc_{air}\frac{\partial T}{\partial t}=Q_{window}+Q_{wall}+Q_{\mathrm{int}}+Q_{tm}+\dot{m}\,c_{air}(T_{ext}-T)$$

- C_{air} = the specific heat capacity of air (KJ/Kg/Fahrenheit)
- m = mass of one roomful of air (Kg)
- $\dot{m}$ = mass flow rate due to ventilation (Kg/sec)
- T = Instantaneous room temperature (Fahrenheit)
- T_{ext} = Outdoor room temperature (Fahrenheit)
- Q_{window} = Heat gain through window (KJ/sec)
- Q_{wall} = Heat gain through wall (KJ/sec)
- Q_{int} = Heat gain through internal loads (KJ/sec)
- Q_{tm} = Heat gain through the thermal mass (KJ/sec)

BUILDING ENERGY SIMULATION

- **Q_{int}** is computed once at the start of each hour and remains constant during that time period.
- The values of **Q_{window}, Q_{wall} and Q_{tm}** are computed at the start of each time step. These loads are assumed constant over the duration of Δt. A conservative **5 minute time step** is currently used in the simulation.
- If a temperature bound is exceeded, heating or cooling HVAC loads are applied to return the zone-air to the upper bound temperature when the air becomes too hot or the lower bound temperature when the air becomes too cool.
- The magnitude of the heating/cooling load is

$$Q_{HVAC} = mc_{air}\left(T_{bound} - T_{t+\Delta t}\right)$$

INTERNAL LOAD (Q_{int})

- Internal loads Q_{int} consist of the sum of heat generated by equipment, artificial lighting and people. Each internal load is modeled as a constant during any given hour.

Floor	Area Type	Percent Area (%)	Design Maximum Occupancy (Sf/person)	Design Ventilation (CF/M/person)	Interior Lighting Loads (W/Sqft)	Office Equipment Loads (W/Sqft)
Ground Floor, Block V	Executive Office	16.3	100	15	0.50	1.0
	Engineering Labs	30.6	100	15	1.00	1.0
	Computer Room	20.8	20	10	1.00	1.0
	Corridor	26.3	100	0	0.15	0.0
	Restrooms	4.0	100	15	0.50	0.0
	Storage	2.0	200	50	0.40	0.0

BUILDING FOOTPRINTS OF BLOCK V – IIT DELHI & HVAC ZONING

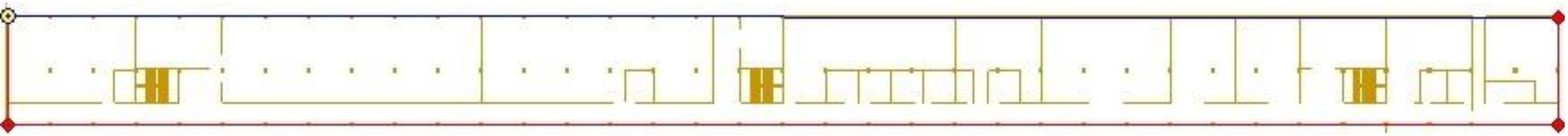


Fig 1(a) Ground Floor Plan, Block V Building, IIT Delhi

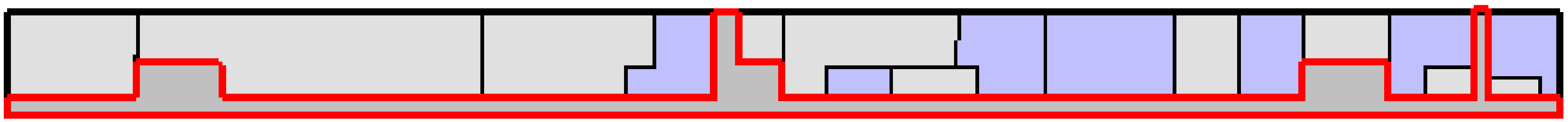


Fig 1(b) Conditioned and Unconditioned zones of the Ground Floor Area of Block V Building

37.1% Conditioned area

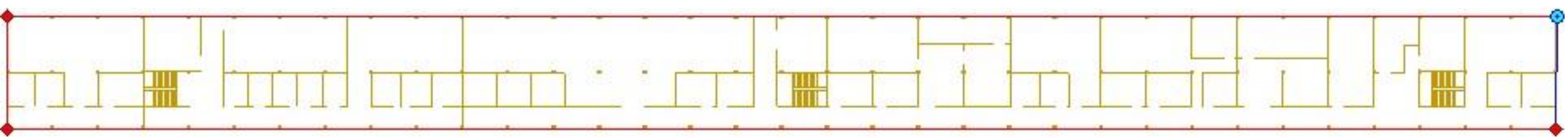


Fig 2 (a) First Floor Plan, Block V Building, IIT Delhi

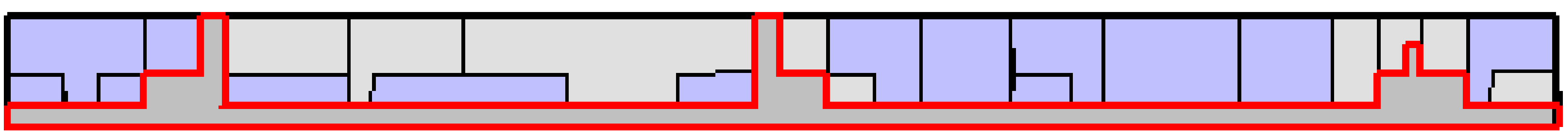


Fig 2(b) Conditioned and Unconditioned zones of the First Floor Area of Block V Building

58.4% Conditioned area

BUILDING FOOTPRINTS OF BLOCK V – IIT DELHI & HVAC ZONING

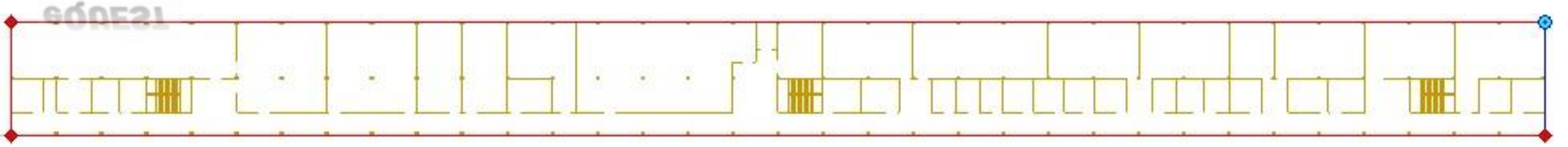


Fig 3(a) Second Floor Plan, Block V Building, IIT Delhi

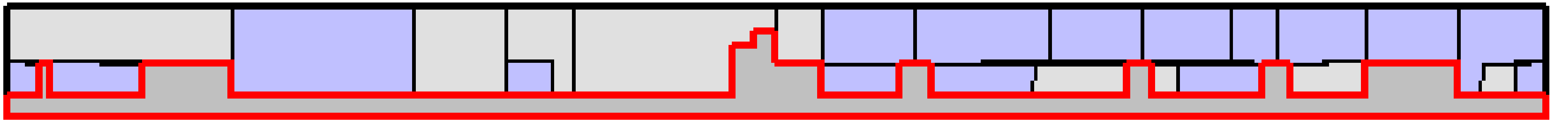


Fig 3(b) Conditioned and Unconditioned zones of the Second Floor Area of Block V Building

63.1% Conditioned area

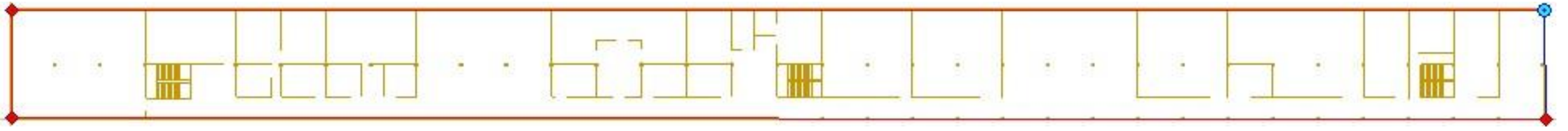


Fig 4(a) Top Floor Plan, Block V Building, IIT Delhi

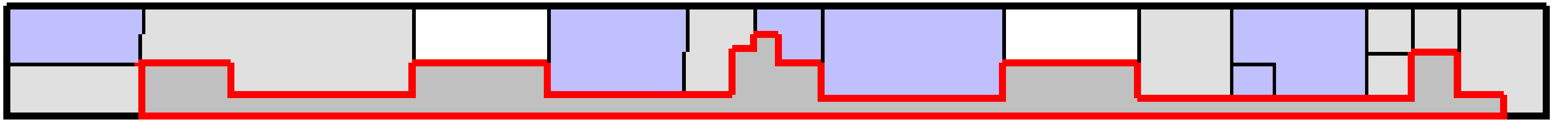


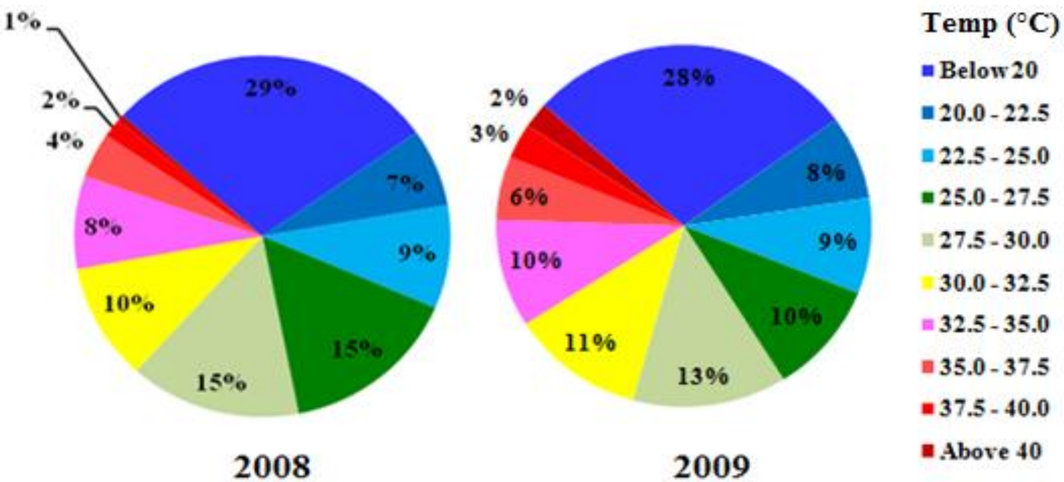
Fig 4(b) Conditioned and Unconditioned zones of the Top Floor Area of Block V Building

19.6% Conditioned area

CONSTRUCTION AND WORKING SCHEME OF BLOCK V BUILDING, IIT D

- The roof construction was of reinforced cement concrete (8 inch) having stone flooring.
- The vertical exterior walls were 14 cm thick were having layer by layer construction viz. plaster - brick masonry - plaster.
- The exterior doors of ground floor, first floor and second floor were opaque and were made of wood while the doors of the top floor were partially (50%) made of glass. The windows were of glass.
- Actual fenestration details in terms of no of door and window opening area.
- The actual HVAC temperature set point in the conditioned zones of the Block V building varied from 25-26°C. Based on this, the HVAC temperature set point for the energy simulation purpose was assumed to be 78°F (25.5°C) for cooling.
- The routine working hours of building which are from 9AM to 6PM were considered for simulating the energy consumption of the building.

MICROMETEOROLOGICAL CHANGES AT IIT DELHI CAMPUS DURING 2008-2009

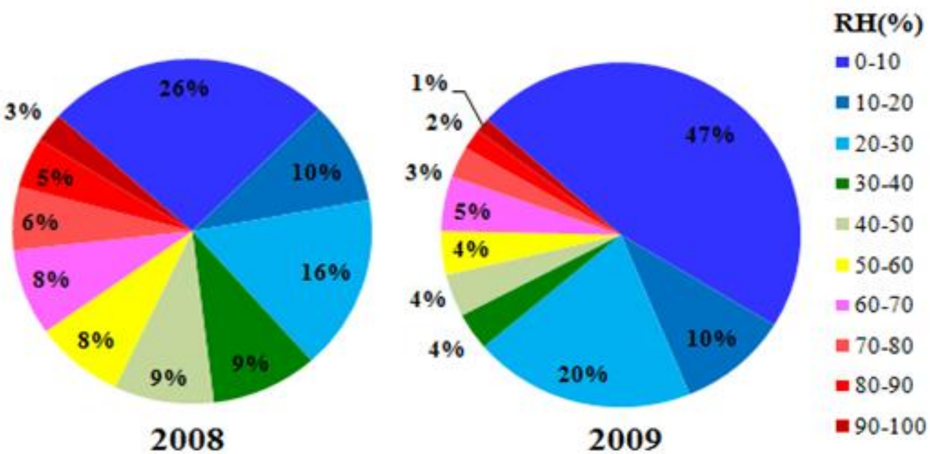


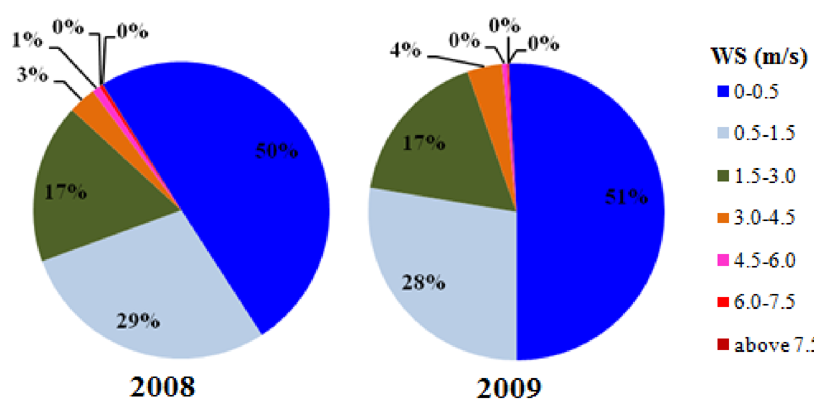
Summary of Met. Changes

Annually averaged Ambient temperature increased by **0.97°C (from 24.48°C to 25.45 °C)**

Annually averaged RH (%) decreased from **36% to 24%**

Annually averaged wind speed decreased from **0.86 m/s to 0.84 m/s**

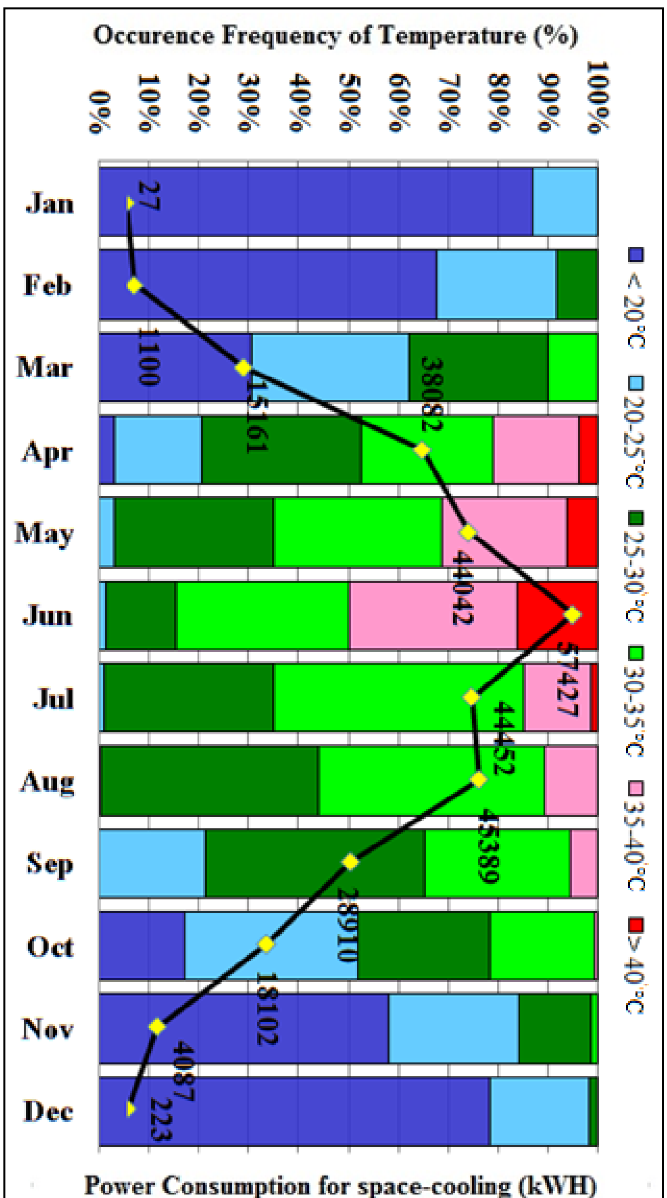


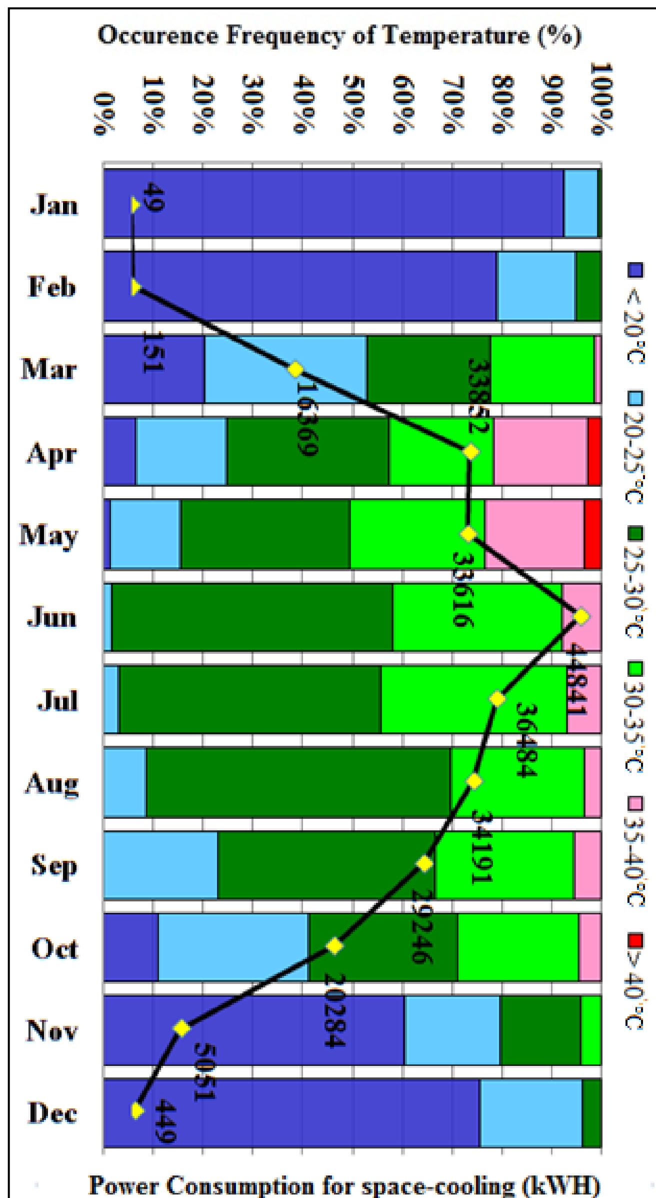


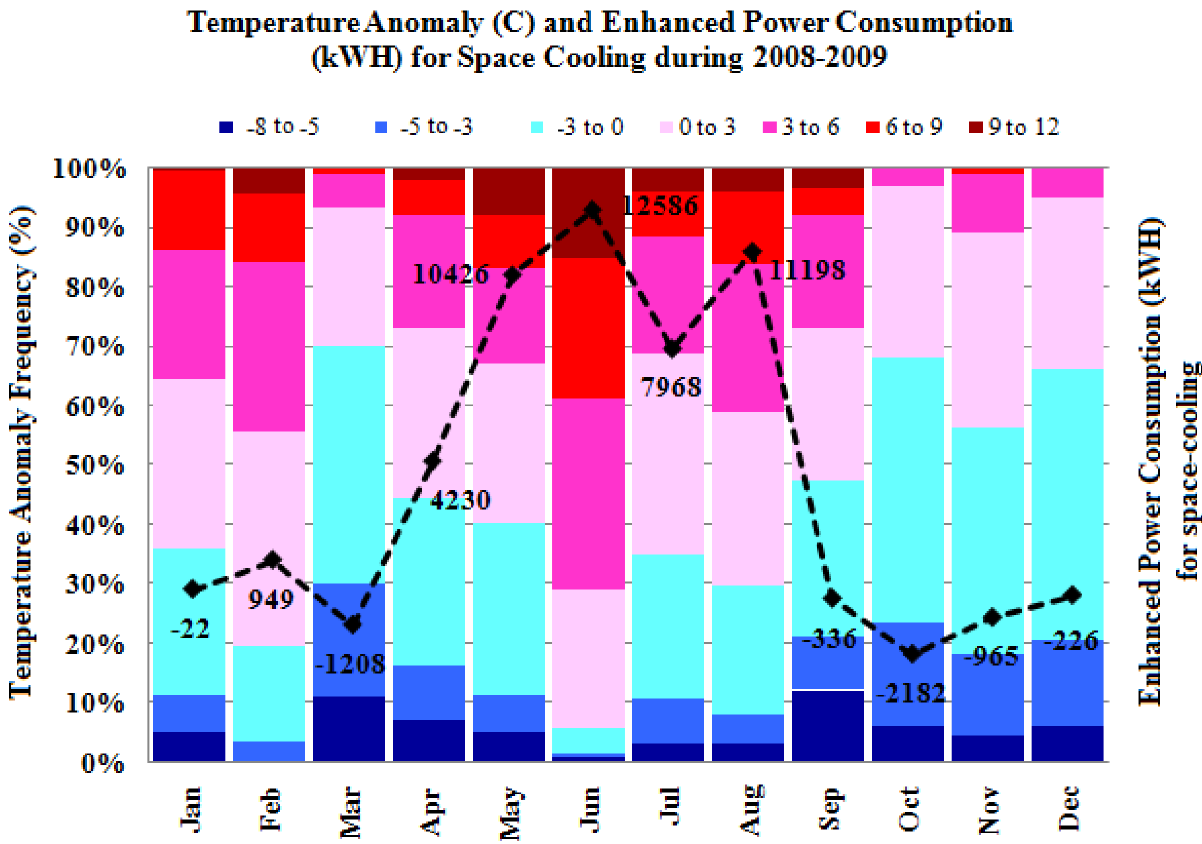
Linking micrometeorological changes at IIT Delhi Campus during 2008-2009 with power consumption for air-conditioning

2009

2008







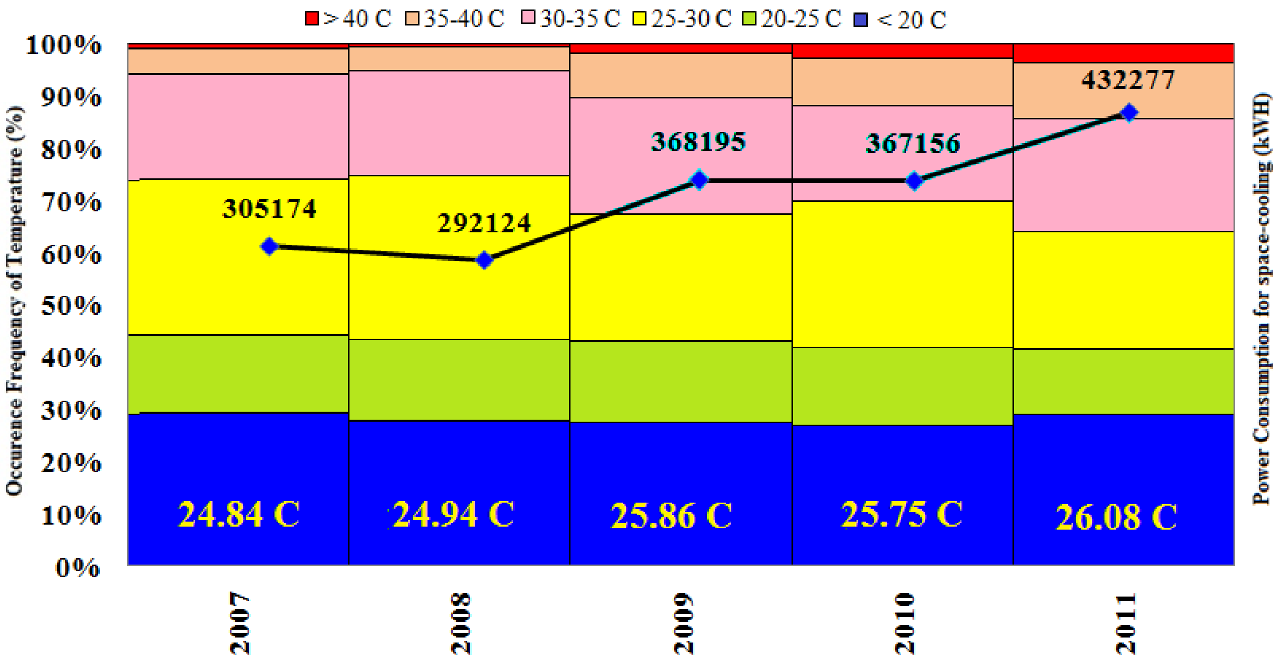
Hourly Temperature Anomaly and its impact of power consumption for space cooling

power consumption for space cooling increased by 16.6%

The simulations infer that the changing meteorological conditions during 2008-2009 increased the annual power consumption for space cooling by **16.6%** (from 254582 kWH in the year 2008 to 297002 kWH in the year 2009) and subsequently the total power consumption increased by **7.67%** (from 5,43,469 kWH in the year 2008 to 5,85,137 kWH in the year 2009).

Interestingly, the actual power consumption of the entire academic area of IIT Delhi campus increased by **7.74%** during this time period (from 151,15,548 kWH in the year 2008 to 162,85,314 in the year 2009).

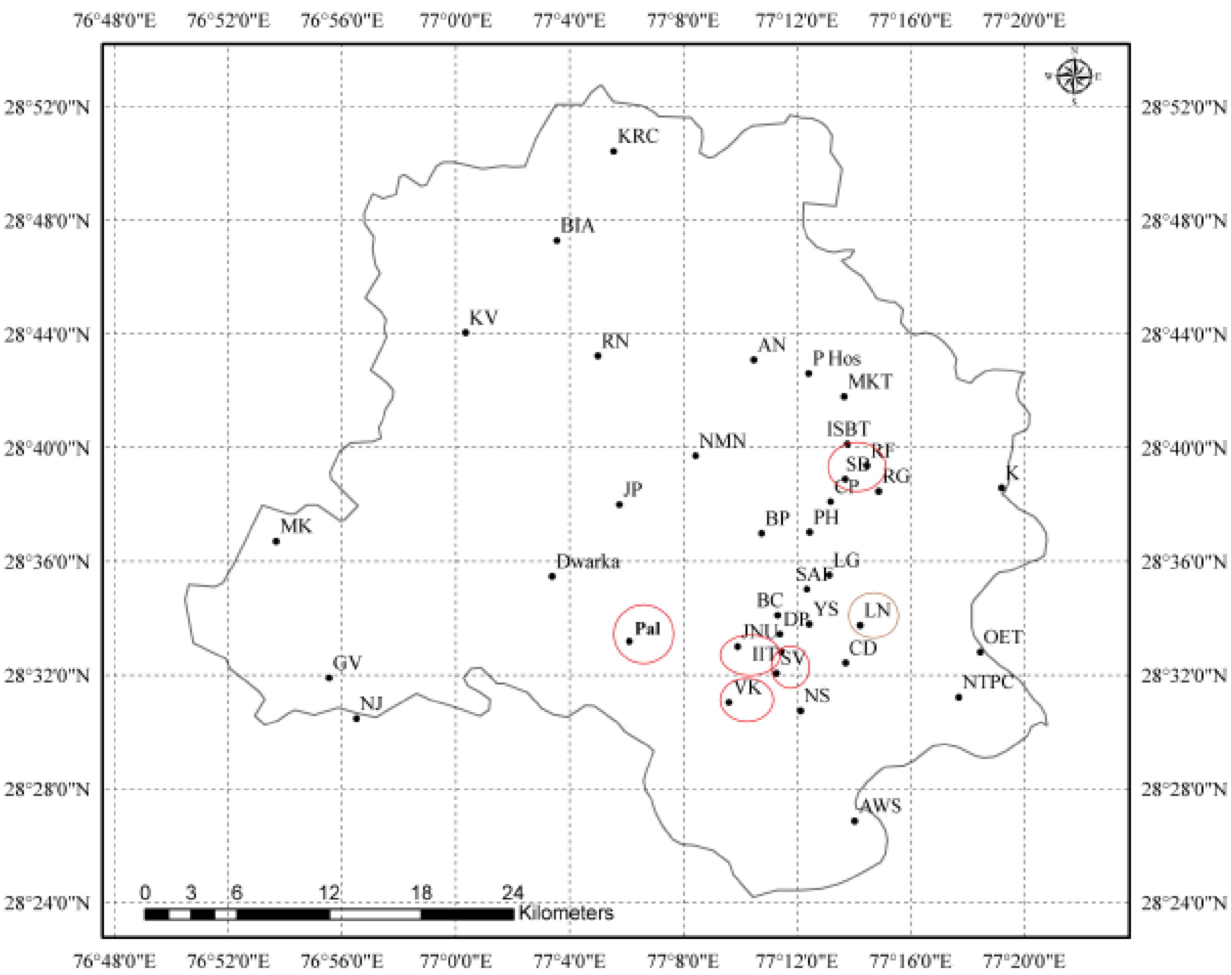
LINKING MICROMETEOROLOGICAL CHANGES AT PALAM AIRPORT DURING 2007-2011 WITH BUILDING ENERGY CONSUMPTION



Power consumption for space cooling **increased** at an average rate of **9.8%** per annum and subsequently Total energy demand has **increased** at the rate of **6.1%** per annum

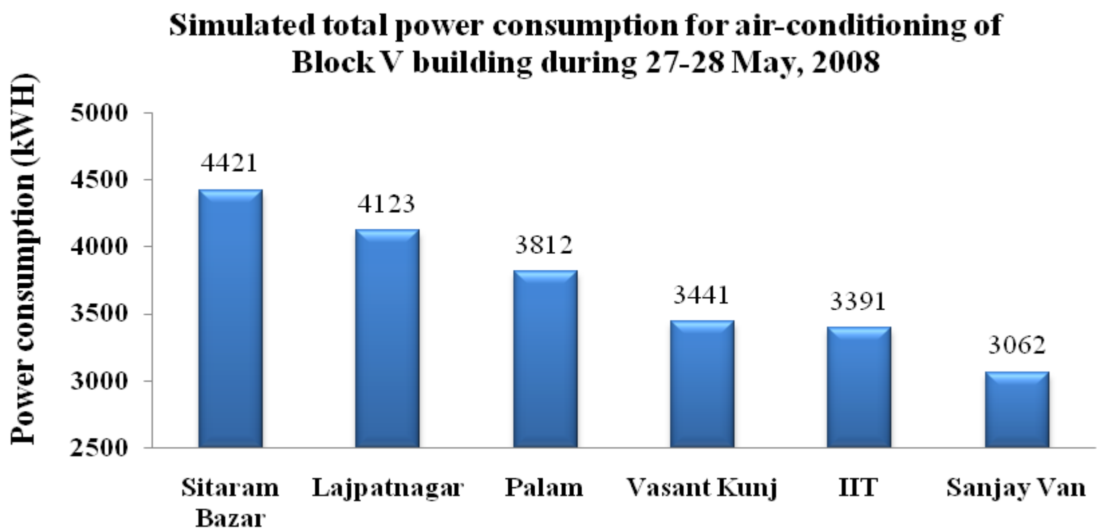
Electric Power Supply of India is **enhancing** the rate of power production for Delhi at the rate of **8%** per annum, a big fraction of this is consumed by the stiffer meteorological conditions leaving less power for fresh developments.

UHI EFFECT AND POWER CONSUMPTION FOR SPACE COOLING



Considering the UHI intensity as calculated from the above campaign, **6 stations viz. Sitaram bazaar, Lajpat Nagar, Palam airport, Vasant Kunj, IIT Delhi and Sanjay Van** were selected for the computation of the cooling load of the Block V Building of IIT Delhi.

UHI EFFECT AND POWER CONSUMPTION FOR SPACE COOLING



In comparison to the ambient temperatures prevailing at Sanjav Van, the ambient temperatures prevailing at Sitaram Bazar, Lajpatnagar, Palam airport, Vasant Kunj and IIT Campus resulted in an enhanced air conditioning load to a tune of **44%, 35%, 25%, 12% and 11% respectively.**

Salior (2002) and **Grimmond (2010)** reported that electricity demand for cooling increases by **3-5%** for every increase in air temperature above **23 ± 1°C**

For maintaining **25.5°C** for **9 hours (9AM-6PM)** in a normal **100 sq Ft room** and the Power Cost @ **Rs 5.87/kWH**, the UHI effect causes an economic burden of **Rs 10, Rs 8, Rs 6, Rs 3 and Rs 2 per day** respectively at the various locations of Delhi.

WAY AHEAD …

We can't stop Urbanization

The only thing we can do is 'through technological interventions' 'infuse sustainability'

I am looking forward for post-doctoral assignments in the areas Urban Climate Modelling and especially in Heat Island Mitigation strategies

Email: akandya@gmail.com
Mobile: +91-9714049800